TNO report
FEL-96-A055

Feasibility Study Measuring Facility for EW-Direction Finders of the Royal Dutch Army

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De DMKL heeft behoefte aan het bepalen van de peilnauwkeurigheid van de peilvoertuigen van het grondgebonden EOV-systeem. Het is de bedoeling de peilnauwkeurigheid van de operationele peilvoertuigen periodiek (1 à 2 jaar) te controleren. Daarnaast zullen de te mobiliseren peilvoertuigen één maal in de vier jaar gecontroleerd worden. Door middel van een uitgebreide meetsessie is eerst ervaring opgedaan met het opzetten van een geschikte meetopstelling. Dit rapport beschrijft de voorbereidingen en resultaten van deze meetsessie die gehouden is in mei 1994 op het terrein van het TNO-FEL.

Tijdens de meetperiode bleek dat grote fouten optraden in de peilresultaten. Om de oorzaak van deze fouten op te sporen zijn veel metingen op verschillende tijdstippen herhaald en op sommige punten uitvoerig bestudeerd. Geconcludeerd kan echter worden dat geen duidelijke oorzaak voor deze fouten kan worden aangewezen. Daarvoor zijn er te veel onzekere factoren aanwezig op het testterrein. Daarom wordt aanbevolen om meerdere meetsessies te houden op verschillende andere terreinen die op grond van hun geschiktheid voor deze metingen worden geselecteerd.

Contents

1 Introduction

The RNLA has a need to determine the accuracy of the direction finders of the ground based EW system of the Royal Dutch Army (see Photo 1.1). The accuracy of the six operational direction finders will be checked periodical once every one or two years. At the start of this project it seemed to be that the TNO-FEL's turntable test site is the right place for these measurements. At first extensive measuring sessions will give practise before a definite calibration site can possibly be set up. The experimental test site is built with the use of presently available means as much as possible.

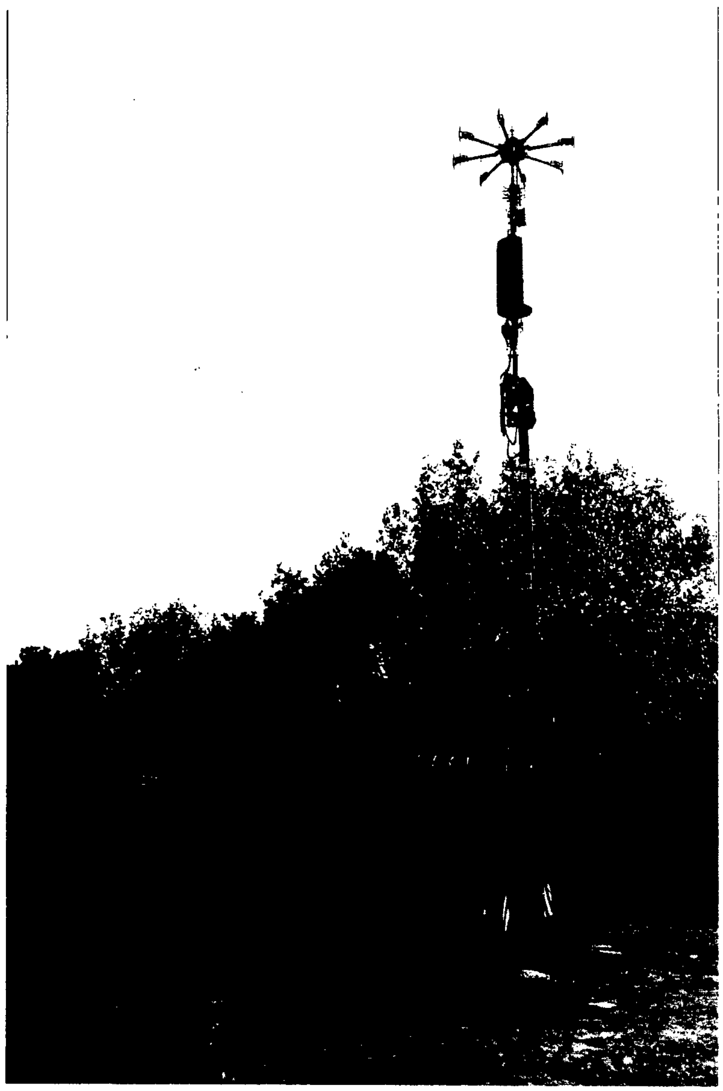


Figure 1.1: The ground based direction finder.

The main goal is to obtain whether or not the FEL test site is suitable for testing the direction finders accuracy. The main question is if this calibration site can offer enough accuracy in order to determine the accuracy of the ground based direction finders.

In order to answer the question whether the direction finders can be checked on a regular base the measurement results must give information about whether or not each measurement can be reproduced, measurement errors can be quantified and the measurements can be performed within an acceptable time period.

In this report, Chapter 2 gives an insight in the role of direction finder in the Electronic Warfare environment. Chapter 3 tells about the development of the FEL test site. Chapter 4 presents the measurement results in such a way that they mainly give an overview of the events that occured during the time the measurements took place. Finally, abbreviations, lessons learned and conclusions are given in Chapter 5.

2 Radio direction finding

Electronic warfare (EW) is an important factor in the combat effectiveness and survival. EW has three main objectives: to gather information about the parties involved in a conflict; to reduce the effectiveness of command, control, communications and reconnaissance; and to maintain the effectiveness of friendly systems, despite intercept or electronic attacks. Specialised EW units are primarily concerned with the first two objectives, while the third is a general responsibility of all forces using electronic equipment.

2.1 Electronic warfare

The brigades and divisions of the RNLA have EW units tasked with exploiting the electromagnetic spectrum and supporting tactical operations, by means of electronic warfare support measures (ESM) and electronic counter measures (ECM). Such units gather tactical and technical information; detect and warn of threats and disrupt and deceive hostile communications and other electronic systems.

The main threat to tactical land forces are combat and combat support units, tactical aircraft and army aviation of parties involved in a conflict. The associated electromagnetic threat comprises both communications and non-communications aspects. Mechanised forces continue to rely primarily on radio for their command, control and communications.

The standard tactical voice and data links used by ground forces and their supporting aircraft operate in the VHF and UHF bands, which are restricted to line of sight operations. Ranges of about 30km for VHF/UHF communications are realistic, if not reduced by terrain. These distances may be extended however, if the transmitter or receiver, or both, are located at elevated positions. Therefore, in order to obtain satisfying conditions, EW units must get close to their targets and use elevated antenna platforms or exploit high terrain, or both.

The upper part of the VHF/UHF bands is often used for multiplex radio relay, both for point to point communications and to form networks. An individual radio relay normally covers distances of 30 to 80km. The use of highly directional antennas, combined with bulk encryption and terrain masking makes it very difficult to employ effective electronic warfare operations.

HF radio normally provides a backup to VHF/UHF communications. Signals in the HF range propagate in two ways, in the form of a ground wave and a sky wave. The effective range of the ground wave is limited to the radio horizon and, depending upon the conductivity of the ground and atmospheric attenuation, generally does not exceed 80km over land. The sky wave portion is reflected by the ionosphere, and may cover distances of 1000 km or more.

At certain distances from the transmitter, however, the ground wave and sky wave interfere. As a result, suitable receiving conditions for the sky wave may not be obtained at distances of less than about 100km from the transmitter. Tactical electronic warfare units in the forward combat zone generally operate on the HF ground wave, leading to similar deployment principles as in the VHF/UHF bands.

Personnel and equipment are organised according to operating positions and functional units: central control/analysis (CCA), intercept centre (IC), direction finding (DF) and jamming/deception (ECM). Equipment is installed in shelters carried on cross country vehicles to ensure the necessary mobility. Power generators are either mounted on the vehicle or carried on separate trailers.

Having received the division operations and the companies mission, the EW company commander, assisted by his headquarters staff and CCA personnel, assesses the situation and prepares his operations order. The CCA supervisor prepares the tasking for the subordinate EW elements on the basis of the company operations order and current requirements of the division. These tasking take the form of an EW Mission List containing the target data, any instructions for the subordinate elements, and the tasking numbers for later reference. The CCA supervisor surveys the relevant parts of the frequency spectrum by carrying out a surveillance search using the ESM receiver. If the signal density is low, adaptive scanning may be used. First, a large band is searched. When the ESM receiver detects an active channel, it reduces the bandwidth in steps and concentrates on the frequencies of interest. This method permits a fast sweep over unoccupied channels. Following his surveillance search, the CCA supervisor allocates selected frequencies or bands to the ESM intercept operators for further action.

2.1.1 Interception

Tasking data are issued verbally by the CCA supervisor, or transferred via the central computer directly into the ESM receivers at the intercept centre. The intercept operators are generally tasked with search and monitoring of predetermined frequency channels or bands, using receivers operating in Frequency Scan Mode. If a receiver detects channel activity, the scanning process stops for a certain period, programmed by the operator. This allows him to decide whether this particular channel should be monitored more closely or not. If the intercept operator decides to intercept a particular channel activity, he starts the recorder and listens in at the same time. He opens an intercept file, makes notes of the radio frequency, time and call sign, and may add verbal comments. When this is completed the intercept operator forwards his report to the CCA.

2.1.2 Direction Finding

The effective location of target emitters by triangulation requires a minimum of three DF systems, arranged along a baseline, taking bearings simultaneously. DF operations are generally controlled centrally by the CCA supervisor, or by the ESM intercept operators. Once commanded by the ESM receiver, direction finding

is initiated either manually or automatically. The ESM receiver's settings are then transferred to the DF systems via UHF radio. The baseline stations automatically take bearing samples of the transmitter and retransmit the data to the CCA central computer, which calculates and displays the transmitter's location.

2.1.3 Counter Measures

ECM operations are generally planned and controlled centrally by CCA personnel, in line with priorities set by the division. Execution may be delegated to the individual ECM system leader if the EW targets cannot be monitored by the EW Operations Centre (EWOC), either because they are too numerous or too far away. The CCA supervisor selects the EW targets and prepares the instructions, which are transmitted to the remote ECM sections by radio, and stored in the memories of their jammers. The jammer system operates in a responsive mode; the monitoring receiver activates the jamming transmitter only if an active channel is detected. It also interrupts the jamming periodically to ensure that the target channel is still active (Look Through mode). The CCA supervisor monitors the hostile communications to verify their presence, and initiates the jamming when appropriate. He then monitors the jamming operation and sends its effectiveness report to the tactical command.

2.2 Expected errors

The basic demands for faultless performance of a direction finder is that the direction finding antenna is situated in an environment that is free from Electro Magnetic Interference (EMI) and there must be a direct line of sight between the transmitter and the direction finding antenna.

Objects, especially those in the vicinity of the antenna, can cause a secondary EM wave (interference) due to reflection of the primary wave. This secondary wave also reaches the antenna and causes additional interference which can cause errors in the direction finding measurements.

When performing direction finding, many different errors can occur. These errors in their turn cause errors in the direction finding measurements. The necessary accuracy of locating a transmitter strongly depends on the purpose for with the direction finding process is performed. For instance, for artillery purposes the location accuracy must be much greater than for gathering information.

The location error is indicated by the root mean square (RMS) error in degrees. The locating accuracy (calculated from taken bearings) can be expressed in the 50% Circle of Probability (CEP). The 50% CEP is the radius of a circle where the transmitter is located with a certainty of 50%. The 50% CEP depends on the RMS error, the distance and the location of the direction finders according to the

transmitter. With a constant locating error, the 50% CEP increases with the distance.

In practise, the errors caused by different sources, will be independent of each other. In general, two types of errors can be distinguished: systematical errors and statistical errors.

2.2.1 Systematical errors

Systematic errors are related with the direction finders equipment and the use of it. The most important sources of systematic errors are:

- Statistical (time independent) errors in direction finding equipment (including the direction finding antenna).
- Inaccurate location of the direction finder.
- Inaccurate bearing reference.
- 'ghost' bearings.

2.2.2 Statistical errors in equipment

These errors can originate from:

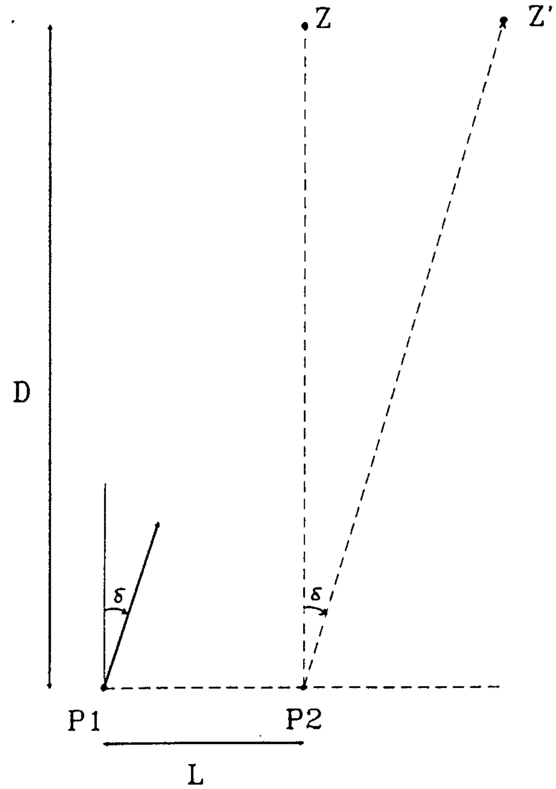
- A mismatch in the antenna element.
- Interference between the antenna elements.
- Unequal signal paths (transition time, phase, amplitude) in the receiver system.

These errors are characterised by the fact that they are steady in time, but dependent on frequency and angle of arrival of the signal. The influence of these errors can be minimised with a thorough calibration of the direction finding equipment. The remainder of the error is given by the manufacturer as the RMS error (this is the RMS error only for the equipment).

2.2.3 Inaccurate location

The accuracy for which the location of the direction finder is known is very important in the direction finding process. Especially at night, location errors can easily be made. When an error is made for the location of the direction finder, a location error of L meters causes a locating error (δ) of arctan(L/D), when the distance to the target is D meters. Figure 2.1 gives an schematic overview of these errors.

Table 2.1 gives an oversight of the maximum bearing error for different location errors and distances of the transmitter. This clearly shows that the bearing error decreases for larger distances.



L = location error
D = distance between direction finder and target
P1 = precise location
P2 = estimated location
Z = precise transmitter location
Z' = appearing transmitter location
δ = locating error (=arctan (L/D))

Figure 2.1: Error between the precise and estimated location.

Table 2.1: Maximum bearing error caused by location errors (1° = 18m).

Location Error \ Distance	10km	20km	30km
50m	0.3°	0.2°	0.1°
100m	0.6°	0.3°	0.2°
200m	1.2°	0.6°	0.4°

These location error can be minimised by:
- Careful navigation/orientation
- Use of accurate navigation equipment
- Choosing a site which has clearly marked reference points

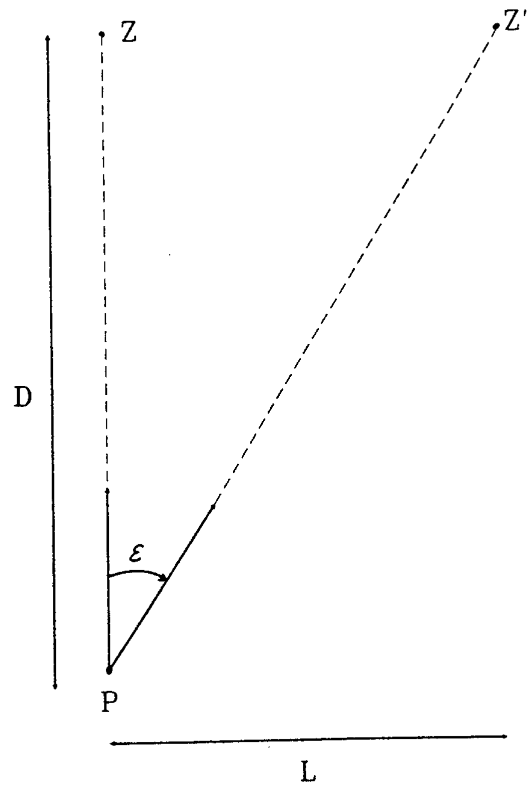
2.2.4 Inaccurate bearing reference:

An inaccurate bearing reference (difference between antenna north and geographic north) greatly increases the error in direction finding. The effect of this type of error is in general much greater than the error caused by an inaccurate direction finder location. An inaccuracy in location causes a constant error in distance (so the error in angle decreases with distance), while an error in bearing reference causes a constant error in bearing, independent of the distance to the transmitter, causing a locating error that increases with distance.

The location error (L), taken from the direction finder location is:

$L = D^{*}\tan \varepsilon$

with ε is the error in bearing reference. This type of error is illustrated in Figure 2.2.



D = distance between direction finder and target
L = locating error
A = direction finder location
ε = error in bearing reference
Z = transmitter location
Z' = apparent transmitter location

Figure 2.2: Error in bearing reference.

In Table 2.2 the apparent target location is shown, related to the true target location, for some errors in angle and distances.

Table 2.2: Variation (m) of error in bearing reference.

Error in angle \ Distance	10km	20km	30km
0.5°	100m	200m	250m
1.0°	200m	350m	500m
0.2°	350m	700m	1000m

It appears in Table 2.2 that for a small error in bearing reference, there appears a relative large error in locating the target. Errors in bearing reference can be minimised by:

- A very accurate magnetic compass. This compass must be set up free from magnetic fields caused by metal objects. In addition the compass must be corrected for the magnetic north at every new location.
- An accurately calibrated gyro compass

An indication of the accuracy of the direction finder location can be obtained by letting different direction finders take bearings of each other (with self transmitted signals). Because environment errors caused by reflections are dependent on frequency, it is necessary that these bearings must be taken for several frequencies.

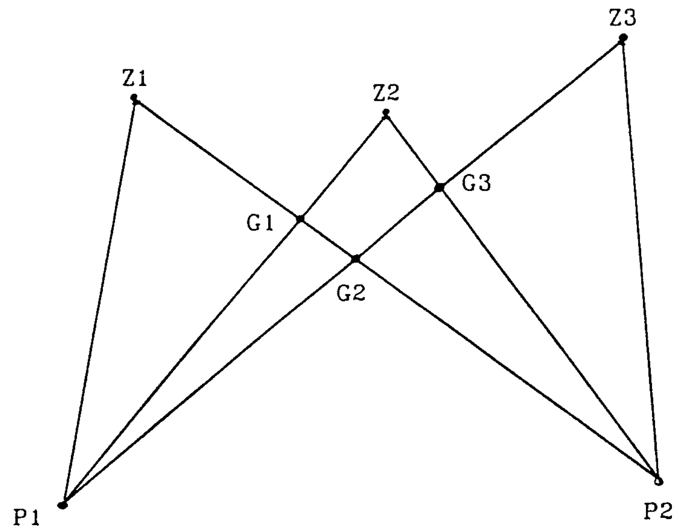
2.2.5 'Ghost' bearings

Ghost targets are targets that appear when data, coming from the direction finders (bearing, frequency, modulation etc.) cannot be assigned to only one target. This effect occurs when some indistinctive bearings do not originate from the same transmitter. After calculations 'ghost' transmitters can be found, as shown in Figure 2.3. 'Ghost' bearings can be looked upon as being statistical errors of the whole direction finding system.

The triangular bearing calculation method can prevent 'ghost' bearings by taking into account more detailed information about the transmitted signal. With this information a distinction can be made between real and 'ghost' bearings results.

2.3 Statistical errors: causes and countermeasures

Other sources of errors can be called statistical errors. These errors are not caused by the direction finding equipment, or the use of it, but originate from the electromagnetic environment itself or the influence that surrounding objects have on it. These statistical errors are dependent of time, frequency and the direction in which a bearing is taken.



P1, P2 = direction finder locations
Z1, Z2 = Transmitter locations
G1, G2, G3 = 'ghost' bearings

Figure 2.3: The appearance of 'ghost' transmitters.

Statistical errors are caused by:
- Noise
- Rounding and approximation errors
- Reflections by surrounding objects

These causes are discussed further in the following.

2.3.1 Noise
Bearings, taken for weak signals, with a low signal to noise ratio (SNR) suffer from a great RMS error. Errors caused by noise cannot be prevented. With a given direction finding system these error can be minimised by locating the direction finder in a way that minimised the attenuation for the transmitter (invoking a maximum SNR). Often this will result in a location as close as possible to the transmitter. Increasing the SNR can, for static or slow moving transmitters, also be achieved by increasing the time in which a bearing is taken. Also, the fact that a bearing is taken with a pour SNR can be taken into account with later calculations. This bearing will then be rated less then other bearings taken from the same signal.

2.3.2 Rounding and approximation errors
Rounding and approximation errors originate from the calculations of the bearing results. This type of error is negligible with today's computer acquipment and processing power.

2.3.3 Multipath effects

Objects, located in the vicinity of the direction finder can reflect the radio signals. This causes, apart from the direct signal, reflected components, coming form different directions. Figure 2.4 shows how these signals reach the direction finding antenna.

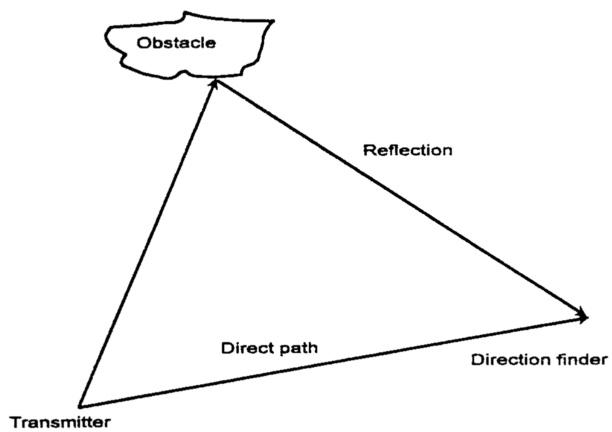


Figure 2.4: Reflection of radio signals in an object.

When the direction finder is placed on a slope, this alone can cause bearing errors also. The most important reflecting objects are:

- Hills
- Buildings
- Vehicles
- Vegetation
- Vertical conductors, such as lampposts and power pylons
- Horizontal conductors, such as fences and power lines

The appearance of reflections can cause large errors in the bearing result, and can even cause statistical and noise errors to be insignificant. In principle, errors caused by reflections in the near site of the direction finder can be rated as statistical errors for a specific location. By extensive calibration of the direction finder for a specific location, and by measuring for a very great number of frequencies and bearings, this error can be compensated. This can somewhat improve the performance for one specific location, but in a tactical scenery this method is not practical. The only possibility to minimise the reflection errors is by choosing a location that is best suitable for direction finding. In practise this decision is highly based on the expertise of the operator on the site.

3 Setting up the TNO-FEL test-site

3.1 Measurements working procedure

The direction finder is measured in the frequency range of 20 to 180MHz, with frequency steps of 1 to 10kHz, depending on the type of measurement. The direction finder is located on a turntable and the positioning of the turntable can be reproduced with an an accuracy of 1°. The VHF calibration transmitter is placed on a small tower near the test site. The resolution of the turntable is suitable for this purpose.

The three receivers of the direction finder are controlled by a computer which can communicate with a command centre via an UHF data communication link. Through this data communication link commands are given to the direction finder, and the bearing and quality information are send to the command centre. A personal computer controls the calibration transmitter via an IEEE controller and also controls the three direction finders and the data acquisition via a modem (RS232). The modem with the UHF transmitter/ receiver is supplied by the Royal Dutch Army. The personal computer also registers the data for future analyses. The controlling of equipment and acquisition of data takes place in a LabWindows software environment.

Each measurement is repeated in order to determine if it can be reliably reproduced. In addition some frequency measurements will be repeated with different power settings for the calibration transmitter. The direction finding accuracy is always measured with a static setting of the turntable while the frequency and power settings of the calibration transmitter is changed.

3.2 Setting up the measurement transmitter

The transmitter is placed on top of a measurement tower and is then set in a fixed position. Two antennas are used, one for each frequency band. The antenna's are directed towards the turntable (see Figure 3.1). During the tests the transmitter power and frequency can be changed and the turntable can be set on any position.

The transmitters are controlled by a computer. The LabWindows processing and control computer controls the measurement sequences. The communication line with the direction finder is build with another computer connected with the same modem/transmitter as is used in the vehicle. The measurement result are displayed on the screen of the modem-PC and then fed into the LabWindows PC (see Figure 3.2).

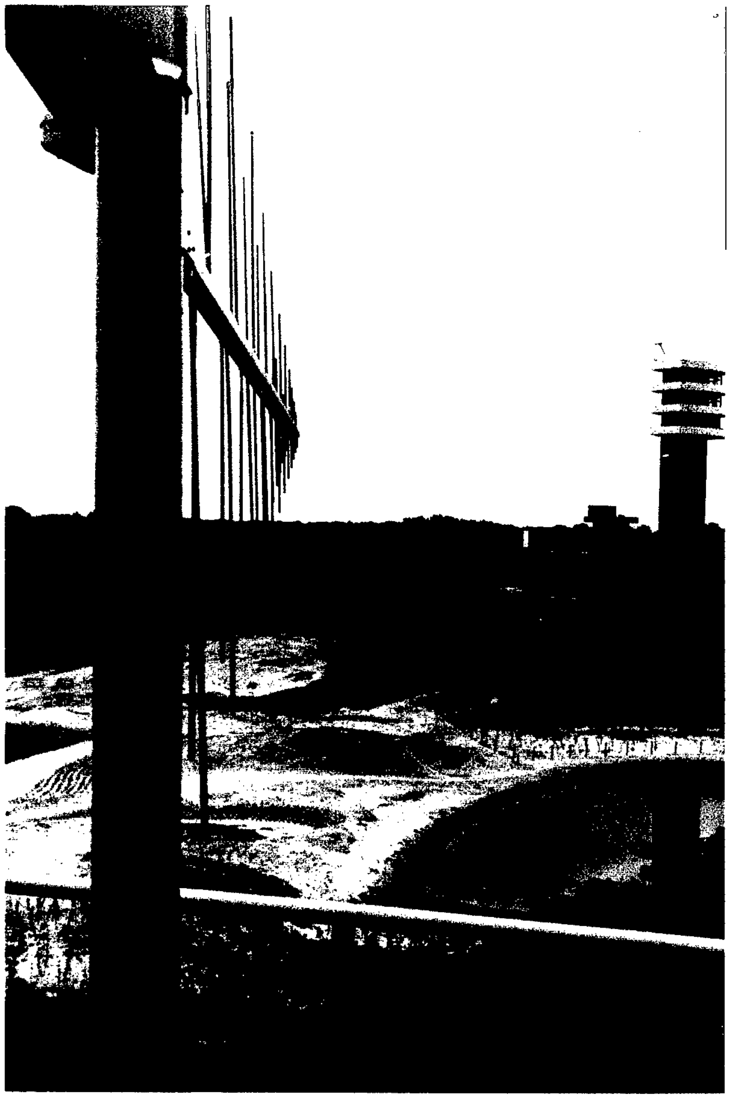


Figure 3.1: One of the two transmitter antennas, pointing in the direction of the turntable.

3.3 Setting up the direction finder

The procedure at the beginning of each measurement session is as follows:

- At first two metal poles are placed in a direct line with the centre of the turntable.
- Then the vehicle drives in a straight line with regard to these poles and is then placed on the turntable. Precise geographic measurements made it possible to place the vehicle on the same spot on the disk with an accuracy of tenths of degrees (within centimetres on the turntable). The disk must be in the 127° position when the vehicle drives on it.
- Then the turntable is rotated to its zero position.
- At this stage the gyro compass of the direction finder is set to zero.
- The gyro compass setting is then once-only set in the system.

Figure 3.2: The transmitters, modem and the two measurement PC's.

With this method the direction finding system 'thinks' the world is spinning around him (see Figure 3.3). In practise, the rotation of the disk (with the vehicle on it) causes the system the experience the transmitter bearing with an equal shift in degrees. The Figures 3.4 and 3.5 show the FEL test site. Figure 3.5 shows the direction finder placed on the turntable and pointing in the direction of the measurement tower.

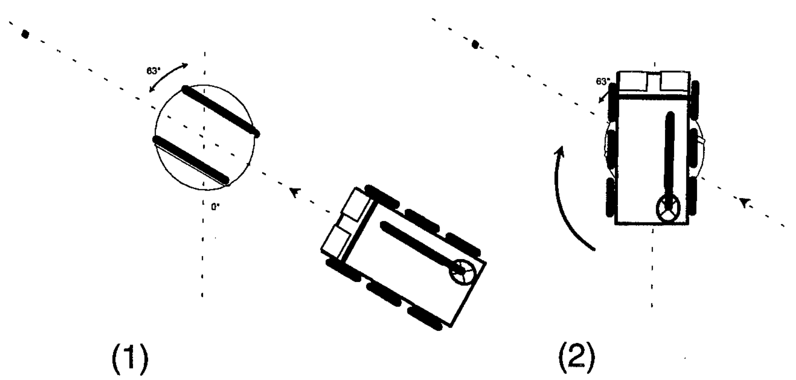


Figure 3.3: Initiation of the measurement sessions. Two metal poles are placed in a direct line with the centre of the disk (the second pole is placed at some distance of the disk and is not drawn in this picture).

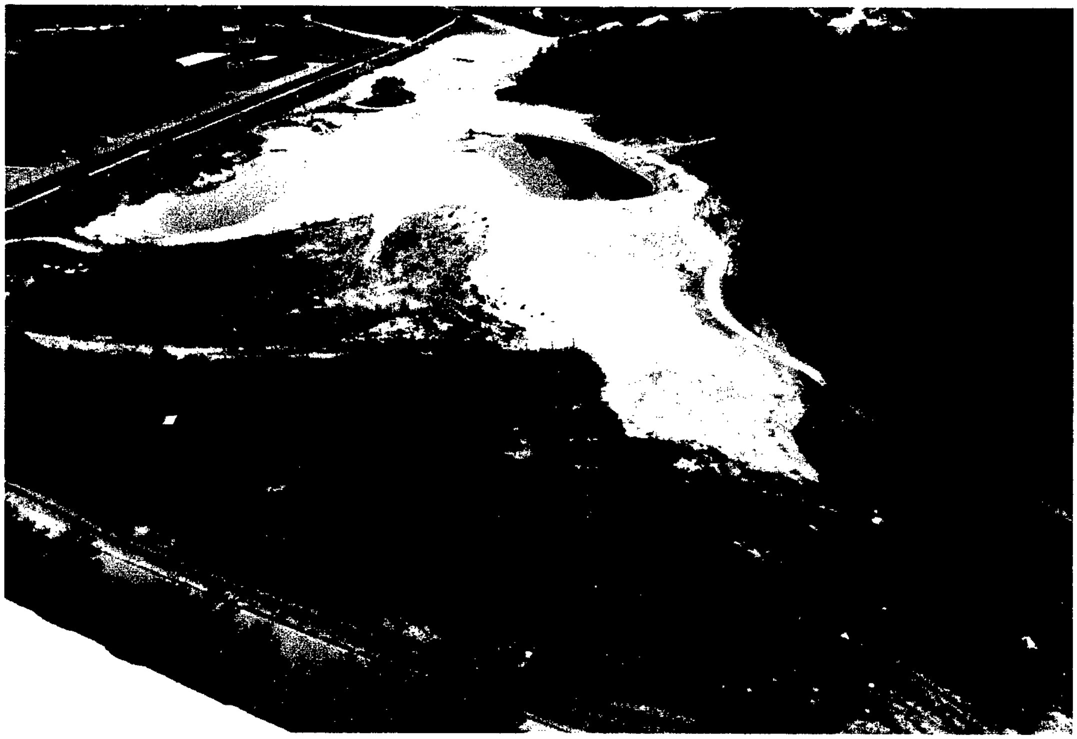


Figure 3.4: The FEL test site. With in the left top corner the measurement tower with the transmitter and in the right bottom corner the turntable (empty).

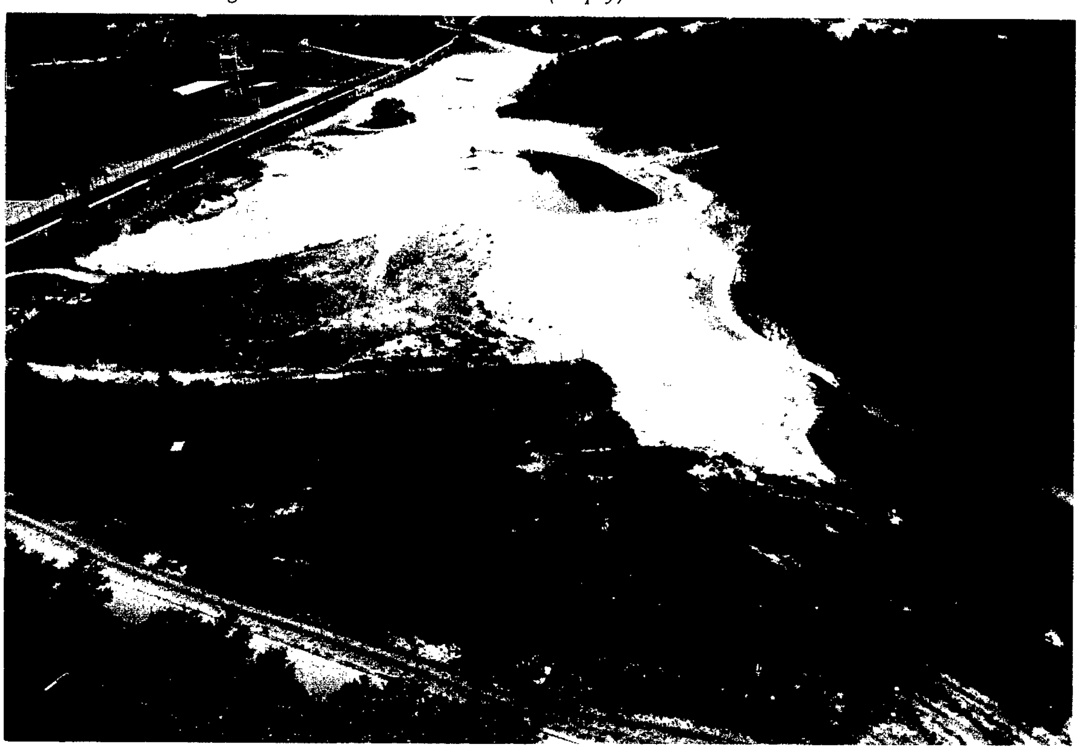


Figure 3.5: The FEL test site, with the direction finder placed on the turntable (right bottom corner) pointing towards the measurement tower (left top corner).

4 Measurements results

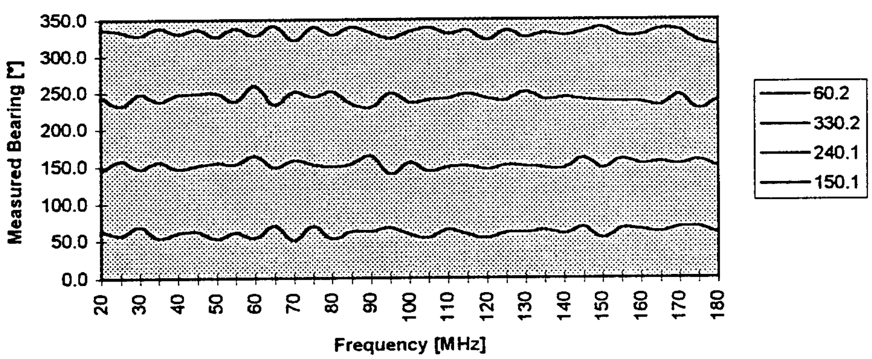
Each measurement result can then be translated in a 'real world' bearing with the following formula:

Real Bearing = 150° - P [mod 360°]

Where P is the measured bearing. In this way each bearing is measured with 0° being in line of sight of the transmitter antenna. So in practise, 0° of the turntable corresponds with the transmitter located on 150° (see Figure 4.7). In the following Tables and Figures the real bearing is often used (calculated from the measurement results) because this gives more insight in the real situation on the test site.

4.1 Frequency measurements of the three direction finding receivers

At first, in order to gain an insight in the behaviour of the direction finder at this location, measurements were taken with the first receiver of the system at 4 different positions of the turntable (89.8°, 179.8°, 269.9° and 359.9°). Figure 4.1 shows the results.



	60.2	330.2	240.1	150.1
Minimum:	49.9	315.5	226.9	138.7
Maximum:	71.4	342.2	259.3	164.8
Average:	61.2	332.0	241.8	152.1

Figure 4.1: Measurements with receiver 1.
Frequency steps: 5MHz
Transmitter power: -6dB

The results show large differences in measured bearings (up to 18.5° with the same rotating disk setting), in spite of the good quality factors given by the system (Q = 1 or 2). In order to investigate this more thoroughly the same measurements are repeated, with the same receiver. The conditions are the same, only this time the turntable was fixed and smaller frequency steps were used within a small frequency band (for practical reasons). The results are presented in Figure 4.2.

Frequency (MHz)	Bearing: 60.2
50.0	51.4
51.0	60.8
52.0	68.0
53.0	67.7
54.0	47.4
55.0	61.7
56.0	68.0
57.0	55.2
58.0	60.8
59.0	71.3
60.0	54.7
61.0	60.5
62.0	64.5
63.0	58.9
64.0	57.3
65.0	71.8
66.0	58.2
67.0	62.2
68.0	67.7
69.0	49.8
70.0	50.3
71.0	67.7
72.0	66.5
73.0	48.6
74.0	65.2
75.0	70.9
76.0	49.4
77.0	60.8
78.0	75.1
79.0	61.5
80.0	72.4

	60.2
Minimum:	47.4
Maximum:	75.1
Average:	61.5

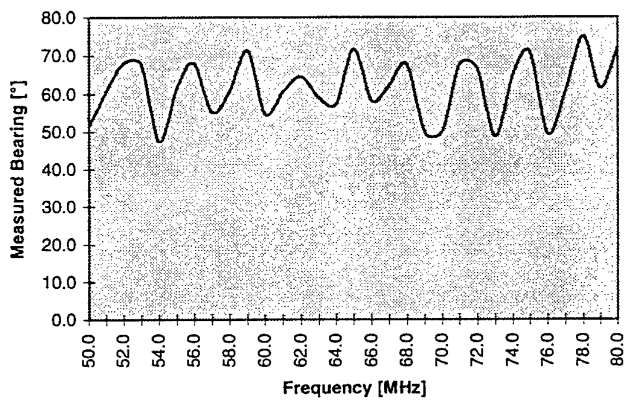


Figure 4.2: Measurements with receiver 1.
Real Bearing: 60.2°
Frequency steps: 1MHz
Transmitter power: -6dB

These results also show great differences in bearing. In order to investigate differences between the three direction finder receivers, the measurements of Figure 4.1 are repeated for receiver 2 and 3. The results are given in Table 4.1 and Figure 4.3.

Table 4.1: *Measurements with receiver 1, 2 and 3.*
Frequency steps: 10MHz
Transmitter power: -6dB

Receiver:	1	2	3	1	2	3	1	2	3	1	2	3
Real Bearing: Frequency:	60.2	60.2	60.2	330.2	330.2	330.2	240.1	240.1	240.1	150.1	150.1	150.1
20	60.8	59.4	61.0	335.7	336.6	337.4	244.9	244.7	245.8	142.3	144.6	143.4
30	70.0	69.5	70.5	328.2	329.3	333.0	247.8	247.5	248.3	146.7	146.5	146.3
40	61.6	61.0	61.5	330.2	331.2	330.5	238.0	246.9	247.8	147.1	147.3	147.0
50	51.9	51.8	52.5	325.6	326.5	326.3	248.7	249.6	249.5	148.3	150.1	149.8
60	54.7	53.5	54.4	328.4	328.1	327.7	249.5	259.2	258.8	165.4	165.1	165.5
70	49.9	49.6	49.5	320.6	321.1	321.1	259.3	251.4	251.7	157.7	157.6	157.4
80	52.1	52.2	53.2	328.4	328.8	328.1	233.3	252.3	252.8	148.5	149.1	148.6
90	62.6	61.7	62.6	330.3	332.3	331.6	243.4	229.4	229.2	163.6	163.9	163.6
100	58.5	59.1	59.8	336.5	335.1	334.2	251.5	237.1	235.2	155.8	154.8	154.3
110	64.5	64.5	65.0	333.7	333.0	332.4	229.1	240.7	241.6	148.3	148.7	148.3
120	63.3	63.0	63.4	322.2	322.1	322.5	249.3	241.5	241.6	145.2	144.4	143.7
130	62.3	60.6	60.9	332.3	327.4	326.4	240.3	250.5	246.6	148.3	148.3	147.6
140	60.1	59.8	60.5	329.8	327.2	327.2	241.6	243.2	243.7	147.6	146.7	146.7
150	53.6	53.6	53.4	341.8	340.4	339.2	241.5	238.3	229.7	149.5	150.3	149.4
160	67.5	65.1	66.2	325.4	328.8	328.2	239.4	238.1	238.7	154.4	153.7	153.2
170	68.4	68.2	67.1	333.1	335.1	335.4	240.0	246.0	246.3	150.5	152.2	152.3
180	58.5	58.4	58.6	313.9	315.3	315.4	243.1	240.0	239.7	150.3	149.4	148.4

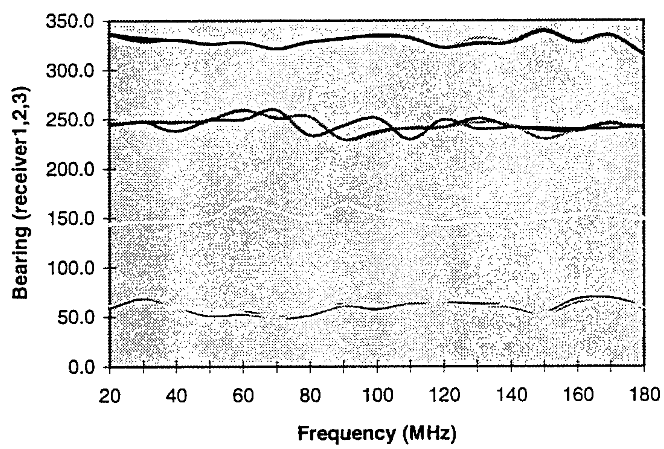


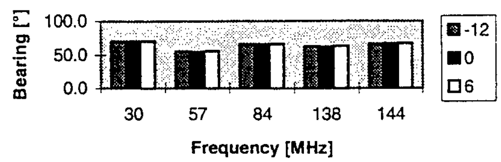
Figure 4.3: *Measurements with receiver 1, 2, 3.*
Frequency steps: 10MHz
Transmitter power: -6dB

The results show only little differences between the three receivers. This means that the large bearing errors are caused by other influences.

4.2 Power measurements for the three receivers

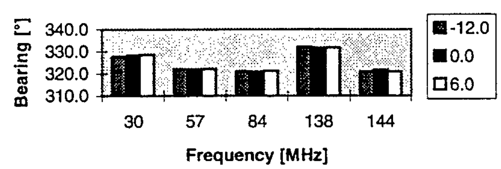
To investigate any influence of transmitter power on the measurements, three different power levels are used in the following measurements (see Figure 4.4). The Figures show now significant differences between the bearing results but errors for different frequencies again are very great. Figure 4.5 shows the differences for the three different receivers.

Transmitter power [dB]:		-12	0	6
Frequency:	30	69.8	70.3	69.9
	57	55.3	54.8	54.9
	84	65.9	65.8	66.1
	138	62.2	61.5	62.8
	144	66.2	66.5	66.3



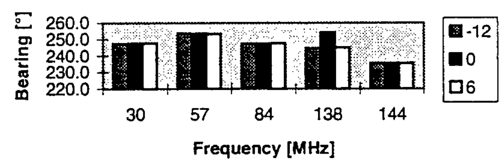
Real bearing: 60.2°
Receiver 1

Transmitter power [dB]:		-12.0	0.0	6.0
Frequency:	30	327.8	328.4	328.6
	57	322.3	322.2	322.1
	84	321.2	320.9	321.2
	138	332.1	331.8	331.8
	144	320.9	321.8	320.9



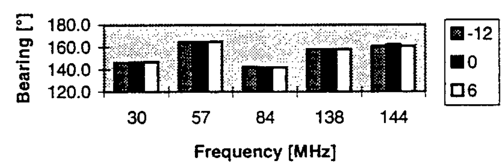
Real bearing: 330.2°
Receiver 1

Transmitter power [dB]:		-12	0	6
Frequency:	30	247.2	247.7	247.8
	57	253.4	253.4	253.3
	84	247.4	247.3	247.6
	138	244.6	254.2	245.1
	144	235.5	235.5	235.3



Real bearing: 240.1°
Receiver 1

Transmitter power [dB]:		-12	0	6
Frequency:	30	146.4	146.8	146.7
	57	164.8	164.7	164.8
	84	142.2	142.1	141.9
	138	158.0	157.9	158.0
	144	161.2	162.2	160.9



Real bearing: 150.1°
Receiver 1

Figure 4.4: Power measurements with receiver 1. Transmitter power: -12, 0 and +6dB

Frequency	Power	1	2	3
30	-12	69.8	69.7	69.5
	0	70.3	69.5	70.1
	6	69.9	69.5	70.2
57	-12	55.3	54.4	54.9
	0	54.8	54.8	55.2
	6	54.9	54.6	55.2
84	-12	65.9	64.8	64.8
	0	65.8	65.7	64.9
	6	66.1	65.5	65.1
138	-12	62.2	61.7	62.5
	0	61.5	61.7	63.5
	6	62.8	61.9	63.1
144	-12	66.2	66.0	66.5
	0	66.5	65.6	66.4
	6	66.3	66.3	67.0

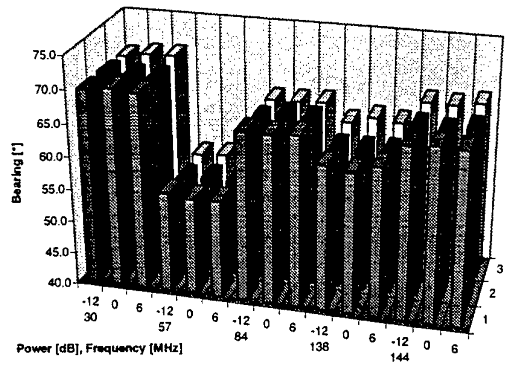


Figure 4.5.a: Different power results for receiver 1, 2 and 3.
Real Bearing: 60.2°
Transmitter power: -12, 0 and +6dB

Frequency	Power	1	2	3
30	-12	327.8	328.8	327.5
	0	328.4	328.6	328.4
	6	328.6	329.1	328.3
57	-12	322.3	321.4	321.6
	0	322.2	320.8	321.4
	6	322.1	322.3	321.5
84	-12	321.2	322.1	321.1
	0	320.9	321.7	321.1
	6	321.2	321.7	321.0
138	-12	332.1	331.2	331.7
	0	331.8	331.8	331.7
	6	331.8	331.8	331.6
144	-12	320.9	321.0	320.6
	0	321.8	320.5	320.8
	6	320.9	320.7	321.0

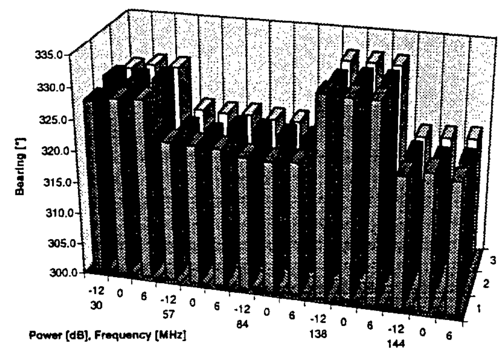


Figure 4.5.b: Different power results for receiver 1, 2 and 3.
Real Bearing: 330.2°
Transmitter power: -12, 0 and +6dB

Frequency	Power	1	2	3
30	-12	247.2	246.8	248.0
	0	247.7	247.5	247.7
	6	247.8	247.6	247.9
57	-12	253.4	252.8	252.7
	0	253.4	253.4	253.0
	6	253.3	253.1	252.7
84	-12	247.4	247.1	246.5
	0	247.3	247.2	247.5
	6	247.6	247.1	247.2
138	-12	244.6	244.1	245.2
	0	254.2	244.6	245.2
	6	245.1	244.4	245.1
144	-12	235.5	235.4	235.5
	0	235.5	235.1	235.2
	6	235.3	235.3	235.3

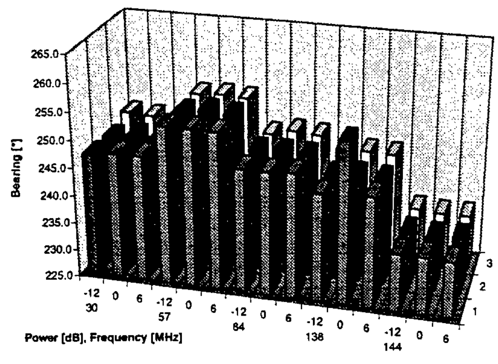


Figure 4.5.c: Different power results for receiver 1, 2 and 3.
Real Bearing: 240.2°
Transmitter power: -12, 0 and +6dB

Frequency	Power	1	2	3
30	-12	146.4	147.3	145.7
	0	146.8	147.3	146.2
	6	146.7	147.1	146.4
57	-12	164.8	165.0	164.4
	0	164.7	164.4	164.4
	6	164.8	164.6	164.3
84	-12	142.2	142.1	141.4
	0	142.1	141.9	141.5
	6	141.9	142.2	141.6
138	-12	158.0	158.3	158.0
	0	157.9	158.0	157.7
	6	158.0	158.4	157.9
144	-12	161.2	161.0	160.8
	0	162.2	160.8	161.2
	6	160.9	160.9	160.8

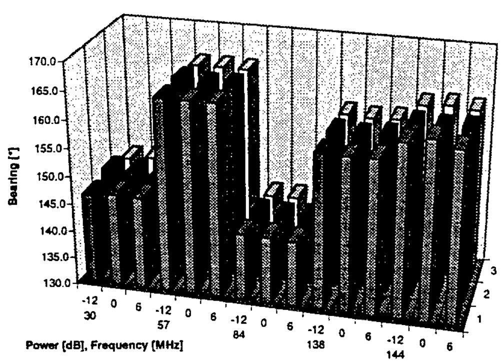


Figure 4.5.d: Different power results for receiver 1, 2 and 3.
Real Bearing: 150.1°
Transmitter power: -12, 0 and +6dB

The measurements with different power levels show no great errors in bearing. Also the differences between the three receivers are not great. Still great errors appear with different frequencies. In order to investigate these errors the turntable with the vehicle placed on it is rotated, while the frequency and transmitter power are fixed. Each measurement is taken for a fixed position of the turntable.

The results for one rotation of the disk (step 20°) are given in Table 4.2.

Table 4.2: Results of bearing measurements of receiver 1, for 360° rotation.
Frequency steps: 20°
Transmitter power: -6dB
(0° = line of sight with transmitter)

Disk:	160.1	180.1	200.0	219.9	240.0	260.0	279.9	299.7	319.9	339.9	359.9	19.9	39.9	60.0	80.1	100.1	120.0	140.0
Real:	349.9	329.9	310.0	290.1	270.0	250.0	230.1	210.3	190.1	170.1	150.1	130.1	110.1	90.0	69.9	49.9	30.0	10.0
20.0	357.6	335.7	314.1	294.4	269.6	255.3	232.8	211.4	188.6	166.3	142.3	121.6	102.7	83.8	67.4	51.6	35.6	17.3
30.0	350.4	328.2	309.2	291.6	274.9	256.8	236.5	215.2	190.4	168.7	146.7	126.5	106.6	90.0	76.3	60.0	39.7	14.8
40.0	350.4	330.2	311.2	290.3	269.7	253.2	240.1	219.8	193.5	169.2	147.1	126.4	106.4	89.6	71.3	51.8	33.2	12.6
50.0	348.4	325.6	304.5	285.5	271.1	257.8	236.7	210.0	187.2	167.0	148.3	134.9	114.4	88.7	58.9	49.6	41.6	18.0
60.0	346.1	328.4	305.4	275.6	258.4	262.6	247.2	203.0	183.3	176.2	165.4	147.4	124.1	82.0	56.3	50.2	35.0	18.5
70.0	346.1	320.6	303.6	286.0	266.9	258.1	238.9	207.0	193.2	179.6	157.7	138.3	117.5	100.8	71.4	35.5	38.6	21.8
80.0	337.5	328.4	314.7	286.6	261.2	261.1	235.7	204.1	198.7	179.5	148.5	123.5	109.1	100.3	73.6	45.6	42.1	17.5
90.0	357.4	330.3	311.1	293.5	278.2	243.7	226.9	216.5	179.0	177.6	163.6	140.4	118.4	93.4	65.4	57.2	27.3	16.5
100.0	343.9	336.5	308.2	292.3	274.8	248.5	228.7	210.8	185.9	177.6	155.8	131.9	112.4	93.3	59.7	58.6	22.8	10.4
110.0	343.6	333.7	312.7	289.4	270.6	246.6	236.5	203.8	190.3	176.5	148.3	120.2	111.8	95.4	75.4	43.5	31.5	12.6
120.0	345.6	322.2	306.4	290.7	264.5	254.3	229.3	207.6	192.5	178.1	145.2	136.2	108.4	90.7	67.7	63.1	22.3	21.4
130.0	341.6	332.3	328.1	291.7	266.3	257.3	233.5	211.6	193.6	175.4	148.3	129.3	104.6	97.7	59.5	66.5	21.0	22.0
140.0	347.5	329.8	320.7	299.9	262.7	253.5	232.8	208.8	192.5	174.4	147.6	127.6	110.4	87.6	63.1	59.3	18.2	19.5
150.0	342.0	341.8	321.1	294.8	262.1	253.6	228.5	210.1	193.4	164.5	149.5	129.8	104.3	90.4	77.1	59.4	16.1	17.3
160.0	354.7	325.4	313.4	297.5	277.7	249.6	225.7	207.1	194.1	170.6	154.4	125.7	113.7	88.6	63.8	47.9	30.4	12.4
170.0	348.8	333.1	312.0	287.6	281.1	254.6	243.6	210.9	188.4	174.6	150.5	133.3	101.8	96.5	73.4	57.5	26.6	13.1
180.0	344.2	313.9	296.4	286.5	276.6	236.8	232.7	206.9	189.3	170.0	150.3	127.1	109.6	87.6	66.8	70.0	33.7	13.3

4.3 Bearing errors

The bearing errors are schematically shown in Figure 4.6.

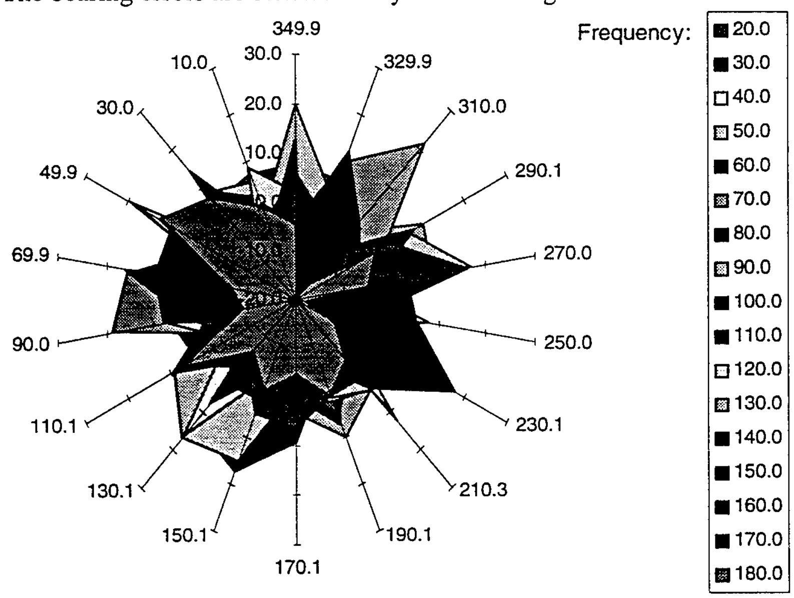


Figure 4.6: Bearing errors with receiver 1.
Fixed frequency and power, disk rotated
Transmitter power: -6dB
(0° = line of sight with transmitter)

Figure 4.6 shows large errors in bearing, appearing randomly in the environment around the vehicle. Figure 4.7 gives average bearing errors for various frequencies around the disk.

Real:	349.9	329.9	310.0	290.1	270.0	250.0	230.1	210.3	190.1	170.1	150.1	130.1	110.1	90.0	69.9	49.9	30.0	10.0
Average:	-0.3	-0.9	-0.8	-0.2	0.4	-0.8	0.2	-0.2	0.0	0.0	0.0	-0.2	0.0	-0.1	-0.2	1.2	0.2	0.2

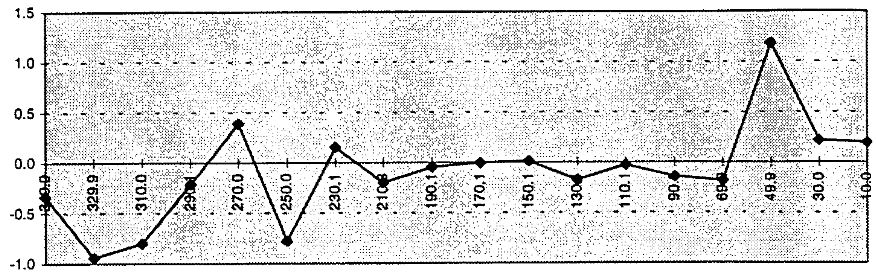


Figure 4.7: Average bearing errors for various frequencies (20-180MHz).
Transmitter power: -6dB
Receiver: 1

The circular scale of Figure 4.8, in degrees, gives the direction in which the direction finder is pointing at the time of the measurements. For instance, when the direction finder is set at 270°, the direction finder is experiencing an average error in bearing measurement of 0.4° (see also Figure 4.7). The results show an average error that lie between -0.9° and +1.2°. This seems to be relatively small, but one must keep in mind that when bearing measurements are taken at specific frequencies much larger errors occur.

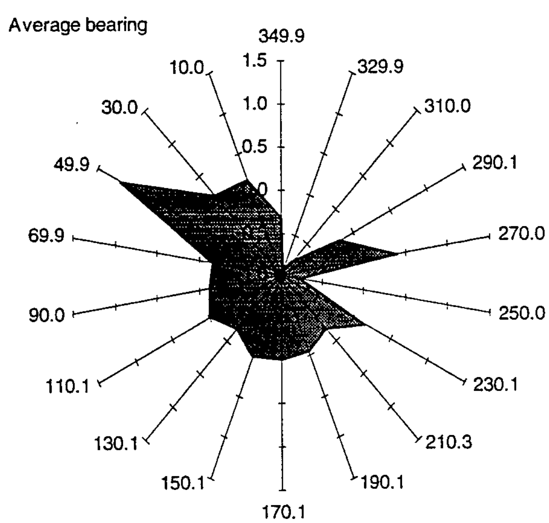


Figure 4.8: Average bearing errors around the direction finder.
(0° = line of sight with transmitter)

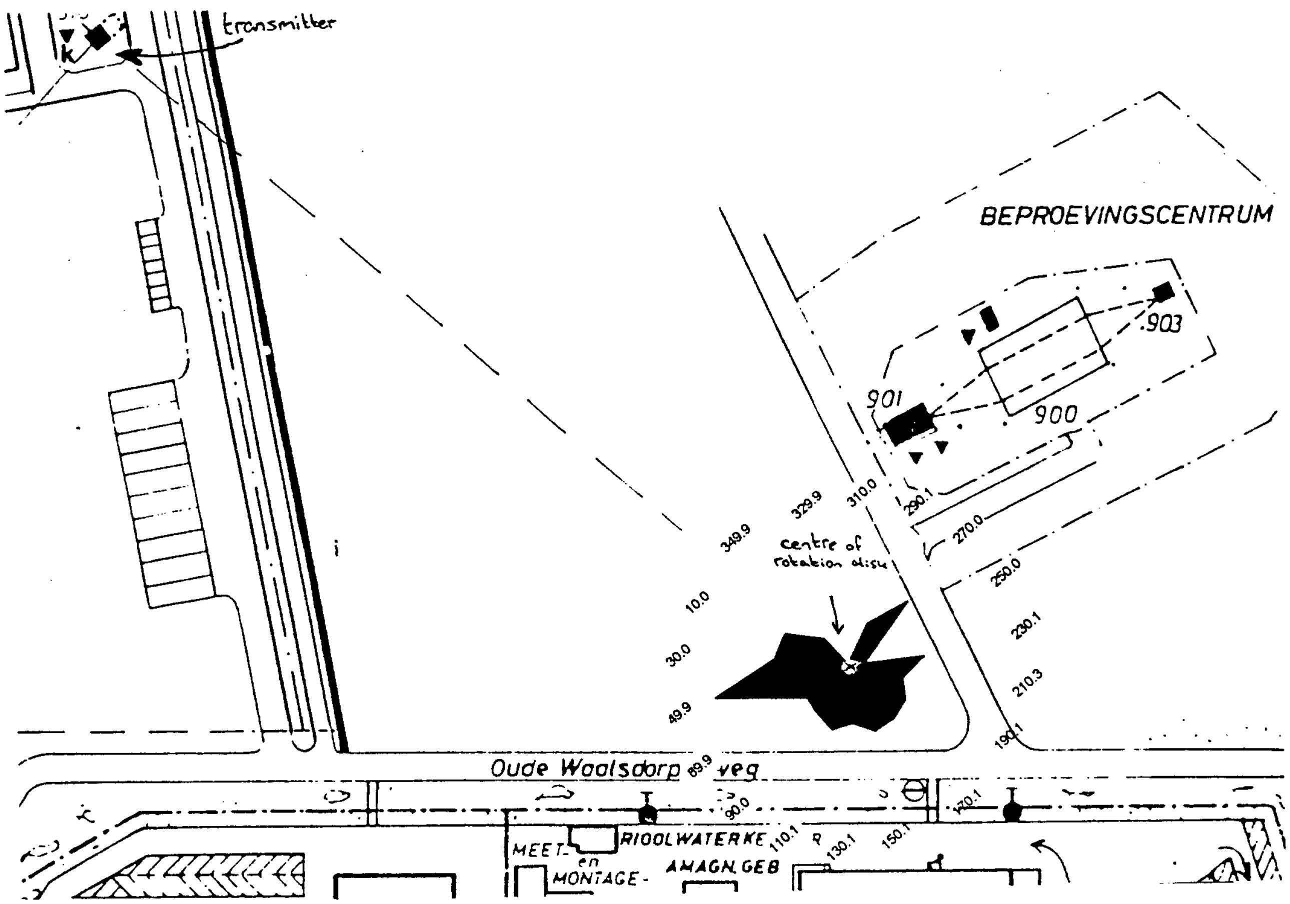


Figure 4.9: Average bearing errors drawn on the geographic map of the FEL test site. (0° = line of sight with transmitter)

Placed on the geographic map of the FEL test site Figure 4.10 shows the same average errors as in Figure 4.9 but now pasted on the actual test site. This gives an some insight in possible influences that interfere with the bearing results. From this Figure one can conclude that the direction finder is experiencing different bearing errors from different sides of the vehicle. Figure 4.10 shows this relationship between the average bearing results and the direction from which the measurement signal is entering the direction finder vehicle.

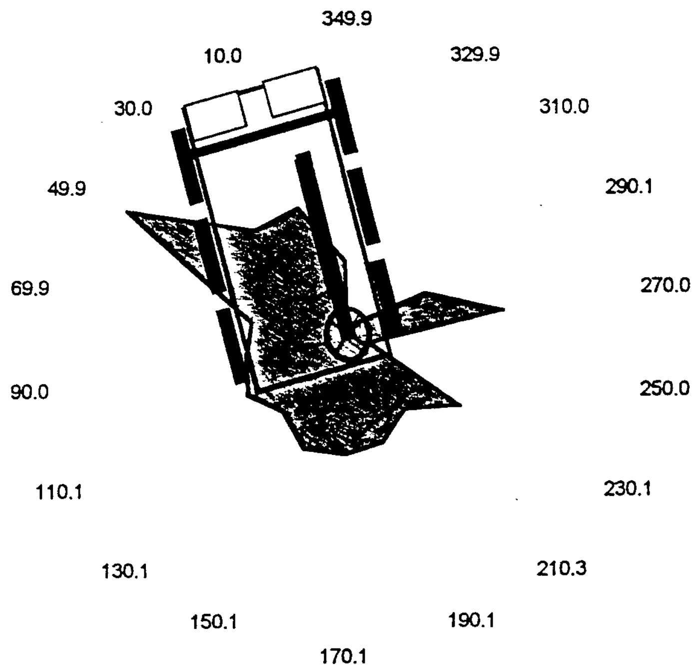


Figure 4.10: Average bearing errors plotted on the direction finder vehicle.

Figure 4.10 shows that some specific spots on the vehicle cause errors. The (flat) rear side and the left side of the vehicle can be indicated as being a source of influence for the bearing measurements.

5 Conclusions/ Lessons learned/ Abbreviations

During the measurement period, the obtained results show quite large errors in bearing. The bearing errors were not so much dependent on the receiver or transmitter power, but much more of the used frequency. Because of the unexpected large errors in the measurement results, the main goal, setting up an accurate calibration test site, is unrealistic for the FEL test site. Within the scope of this project it was not possible to determine the precise causes of these errors.

Some possible sources can be:

- The surrounding environment of the FEL test site.
  In the surrounding of the transmitter and the turntable there are many poles, fences, buildings, small hills and water. They all have great influence on the direction finding results.
- The direction finding receiver. Not much experience has been gained with the direction finder itself. At least not in a comparable test environment.
- The direction finding vehicle. This is made of metal, and being close to the receiving antenna of the direction finder it can be a source of reflections (see Figure 5.1).

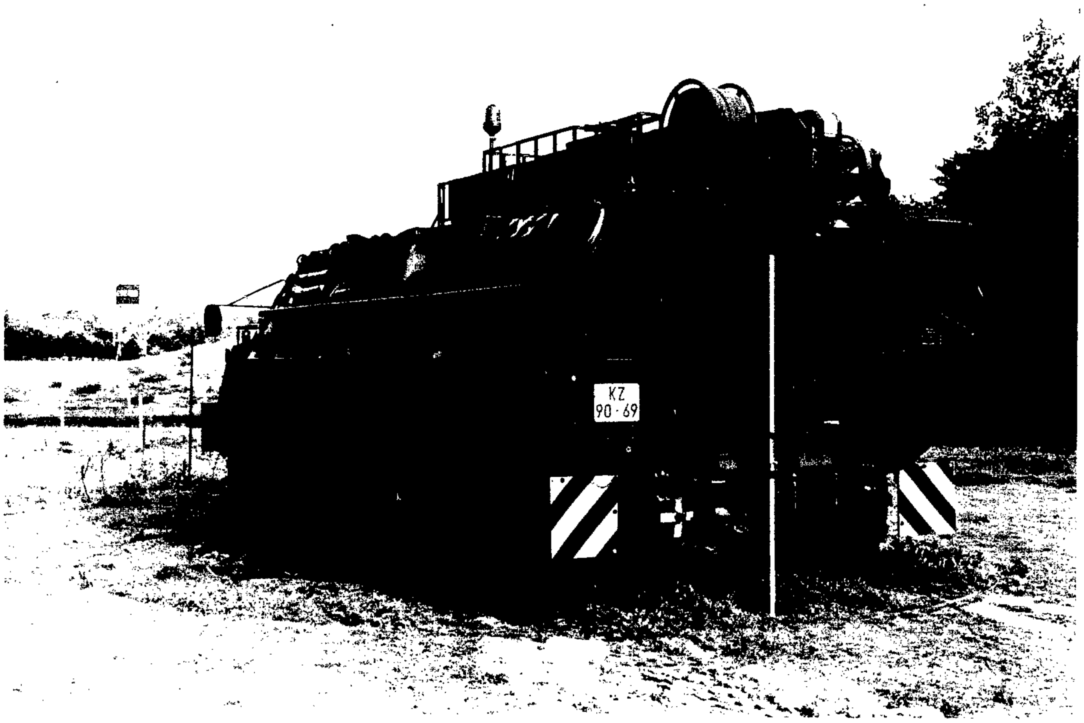


Figure 5.1: Close-up photo of the direction finder.

In order to get a better insight in the performance of the land based direction finder in the future, it is necessary to test these systems in different surroundings. Some that look like the FEL test site, for comparison with the results that are presented in this report. Other test sites can be chosen which seem ideal for direction finding purposes from the theoretical point of view or which seem ideal by the actual operators of the system. Then, in practise, the accuracy of the direction finding system can be recorded under real operational conditions. These results can act as a base for setting up the demands for a practical an accurate measurement facility. However, because of the numerous interference sources one must always keep in mind that finding an ideal calibration site for direction finding systems is very hard, even if it is built under laboratory conditions.

6 References

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7 Signature

J.J.A. Klaasen
Group leader

M.G. Cornet
Author

Appendix A Frequency measurements for direction finding receiver 1

Transmitter power: -6dB

		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:	19_9_F1	5/25/94	39_9_F1	5/25/94	60_0_F1	5/25/94	80_1_F1	5/25/94	89_8_F1	5/26/94
Disk setting:	19.9	11:26:13	39.9	12:30:17	60	12:46:39	80.1	13:00:30	89.8	12:23:33
Rounded disk setting:	20		40		60		80		90	
Calculated real bearin	130		110		90		70		60	
Frequency [MHz]:										
20	121.6	2	102.7	2	83.8	2	67.4	2	64.4	5
30	126.5	1	106.6	1	90	2	76.3	2	69.8	1
40	126.4	1	106.4	1	89.6	1	71.3	1	61	1
50	134.9	1	114.4	2	88.7	2	58.9	1	52.4	1
60	147.4	2	124.1	3	82	4	56.3	1	54	1
70	138.3	1	117.5	1	100.8	1	71.4	3	49.9	2
80	123.5	2	109.1	3	100.3	1	73.6	2	52.9	1
90	140.4	1	118.4	2	93.4	2	65.4	1	62.8	1
100	131.9	1	112.4	3	93.3	2	59.7	2	58.7	2
110	120.2	1	111.8	2	95.4	1	75.4	1	64.7	2
120	136.2	1	108.4	2	90.7	1	67.7	1	53.2	2
130	129.3	1	104.6	2	97.7	1	59.5	1	61.4	2
140	127.6	1	110.4	1	87.6	2	63.1	1	59.8	2
150	129.8	1	104.3	1	90.4	1	77.1	1	53.2	1
160	125.7	1	113.7	1	88.6	2	63.8	1	65.1	1
170	133.3	1	101.8	2	96.5	2	73.4	1	68	1
180	127.1	2	109.6	1	87.6	1	66.8	2	59.7	3

Transmitter power: -6dB

		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:	89_8_F1	5/26/94	89_8_F1	5/26/94	100_1_F1	5/25/94	120_0_F1	5/25/94	140_0_F1	5/25/94
Disk setting:	12:41:20	89.8	89.8	12:52:26	100.1	13:14:14	120	13:26:42	140	14:06:06
Rounded disk setting:	90		90		100		120		140	
Calculated real bearin	60		60		50		30		10	
Frequency [MHz]:										
20			60.8	3	51.6	2	35.6	2	17.3	4
30			70	1	60	1	39.7	2	14.8	2
40			61.6	1	51.8	1	33.2	1	12.6	1
50	51.4	1	51.9	1	49.6	2	41.6	1	18	2
60	54.7	1	54.7	1	50.2	1	35	1	18.5	2
70	50.3	2	49.9	2	35.5	1	38.6	2	21.8	2
80	72.4	1	52.1	1	45.6	2	42.1	1	17.5	2
90			62.6	1	57.2	1	27.3	2	16.5	2
100			58.5	2	58.6	1	22.8	3	10.4	2
110			64.5	2	43.5	2	31.5	2	12.6	1
120			63.3	2	63.1	1	22.3	1	21.4	1
130			62.3	2	66.5	2	21	1	22	1
140			60.1	2	59.3	1	18.2	1	19.5	1
150			53.6	1	59.4	2	16.1	2	17.3	1
160			67.5	3	47.9	2	30.4	1	12.4	1
170			68.4	1	57.5	1	26.6	1	13.1	1
180			58.5	3	70	1	33.7	2	13.3	1

Transmitter power: -6dB

		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:	160_1_F1	5/25/94	179_8_F1	5/26/94	180_1_F1	5/25/94	200_0_F1	5/25/94	219_9_F1	5/25/94
Disk setting:	160.1	14:19:18	179.8	13:36:47	14:33:41	180.1	200	14:45:21	219.9	14:55:04
Rounded disk setting:	160		180		180		200		220	
Calculated real bearin	350		330		330		310		290	
Frequency [MHz]:										
20	357.6	4	336.5	3	335.7	3	314.1	3	294.4	3
30	350.4	2	328.5	2	328.2	2	309.2	2	291.6	2
40	350.4	2	330.9	1	330.2	1	311.2	1	290.3	1
50	348.4	2	326.6	1	325.6	1	304.5	1	285.5	1
60	346.1	1	328.6	1	328.4	1	305.4	2	275.6	1
70	346.1	2	321.4	1	320.6	1	303.6	1	286	1
80	337.5	1	328.8	1	328.4	2	314.7	2	286.6	2
90	357.4	1	331.9	2	330.3	1	311.1	1	293.5	1
100	1.9	3	334	3	336.5	3	308.2	1	292.3	2
110	343.6	1	331	2	333.7	2	312.7	2	289.4	1
120	345.6	3	322.5	1	322.2	2	306.4	1	290.7	1
130	341.6	1	326.1	4	332.3	3	328.1	2	291.7	3
140	347.5	2	328.1	1	329.8	3	320.7	2	299.9	2
150	342	2	339.6	2	341.8	1	321.1	1	294.8	1
160	354.7	1	329.3	1	325.4	1	313.4	1	297.5	2
170	348.8	1	336	1	333.1	1	312	2	287.6	1
180	4.2	2	315.5	2	313.9	2	296.4	1	286.5	1

Transmitter power: -6dB

		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:	240_0_F1	5/25/94	260_0_F1	5/25/94	269_9_F1	5/26/94	279_9_F1	5/25/94	299_7_F1	5/26/94
Disk setting:	240	15:04:52	260	15:17:47	269.9	14:30:00	279.9	15:28:52	299.7	9:50:21
Rounded disk setting:	240		260		270		280		300	
Calculated real bearin	270		250		240		230		210	
Frequency [MHz]:										
20	269.6	6	255.3	2	244.9	4	232.8	2	211.4	2
30	274.9	1	256.8	1	247.8	1	236.5	1	215.2	1
40	269.7	1	253.2	2	247.5	1	240.1	1	219.8	1
50	271.1	1	257.8	1	249.5	1	236.7	1	210	1
60	258.4	3	262.6	3	259.3	1	247.2	2	203	3
70	266.9	2	258.1	1	251.6	1	238.9	2	207	1
80	261.2	1	261.1	2	251.5	1	235.7	2	204.1	1
90	278.2	1	243.7	2	229.1	1	226.9	2	216.5	2
100	274.8	2	248.5	2	236.7	1	228.7	2	210.8	1
110	270.6	1	246.6	1	241.6	2	236.5	2	203.8	1
120	264.5	1	254.3	1	241.5	1	229.3	1	207.6	2
130	266.3	1	257.3	1	251.2	1	233.5	2	211.6	2
140	262.7	3	253.5	3	243.1	1	232.8	2	208.8	1
150	262.1	3	253.6	2	238.7	1	228.5	1	210.1	1
160	277.7	1	249.6	3	237.1	2	225.7	3	207.1	1
170	281.1	1	254.6	2	246.4	1	243.6	2	210.9	1
180	276.6	1	236.8	1	240.4	2	232.7	1	206.9	1

Transmitter power: -6dB

		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:	319_9_F1	5/26/94	339_9_F1	5/26/94	359_9_F1	5/26/94	359_9_F2	5/26/94
Disk setting:	319.9	10:19:24	339.9	10:30:43	359.9	10:40:03	359.9	15:20:53
Rounded disk setting:	320		340		360		360	
Calculated real bearin	190		170		150		150	
Frequency [MHz]:								
20	188.6	3	166.3	1	142.3	1	144.7	3
30	190.4	1	168.7	1	146.7	1	146.9	1
40	193.5	1	169.2	1	147.1	1	146.8	1
50	187.2	1	167	1	148.3	1	154.3	1
60	183.3	1	176.2	2	165.4	2	164.8	2
70	193.2	1	179.6	2	157.7	2	158.3	1
80	198.7	1	179.5	3	148.5	2	149.9	2
90	179	1	177.6	2	163.6	1	164.4	1
100	185.9	2	177.6	2	155.8	1	155.3	1
110	190.3	1	176.5	2	148.3	1	149.4	2
120	192.5	1	178.1	1	145.2	2	145.9	2
130	193.6	1	175.4	1	148.3	2	150.1	2
140	192.5	1	174.4	1	147.6	2	147.2	1
150	193.4	2	164.5	2	149.5	3	147.3	3
160	194.1	1	170.6	1	154.4	2	152.8	2
170	188.4	2	174.6	2	150.5	1	152.4	1
180	189.3	1	170	1	150.3	1	149	1

Appendix B Additional frequency measurements for direction finding receiver 1

Repeated measurments on different point of time.

Transmitter power: -6dB			Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:		89_8_F1	5/26/94	89_8_F1	5/26/94	89_8_F1	5/26/94
Disk setting:		89.8	12:23:33	12:41:20	89.8	89.8	12:52:26
Rounded disk setting:		90			90	90	
Calculated real bearing:		60			60	60	
Frequency:	20	64.4	5			60.8	3
	25	57.4	2				
	30	69.8	1			70	1
	35	53.4	1				
	40	61	1			61.6	1
	45	62.2	1				
	50	52.4	1	51.4	1	51.9	1
	55	61.8	2	61.7	2		
	60	54	1	54.7	1	54.7	1
	65	71.4	1	71.8	1		
	70	49.9	2	50.3	2	49.9	2
	75	70.6	1	70.9	1		
	80	52.9	1	72.4	1	52.1	1
	85	62.6	2				
	90	62.8	1			62.6	1
	95	67	2				
	100	58.7	2			58.5	2
	105	53.8	1				
	110	64.7	2			64.5	2
	115	58.5	1				
	120	53.2	2			63.3	2
	125	61.2	2				
	130	61.4	2			62.3	2
	135	64	1				
	140	59.8	2			60.1	2
	145	68.2	1				
	150	53.2	1			53.6	1
	155	66.5	1				
	160	65.1	1			67.5	3
	165	61.9	1				
	170	68	1			68.4	1
	175	67.8	1				
	180	59.7	3			58.5	3

Repeated measurments on different point of time.

Transmitter power: -6dB			Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:		179_8_F1	5/26/94	269_9_F1	5/26/94	180_1_F1	5/25/94
Disk setting:		179.8	13:36:47	269.9	14:30:00	180.1	14:33:41
Rounded disk setting:		180		180		180	
Calculated real bearing:		330		330		330	
Frequency:	20	336.5	3	244.9	4	335.7	3
	25	333.4	3	231.6	1		
	30	328.5	2	247.8	1	328.2	2
	35	339	1	238	2		
	40	330.9	1	247.5	1	330.2	1
	45	336.7	1	248.7	1		
	50	326.6	1	249.5	1	325.6	1
	55	338.8	2	237.8	1		
	60	328.6	1	259.3	1	328.4	1
	65	342.2	1	233.3	3		
	70	321.4	1	251.6	1	320.6	1
	75	340.6	2	243.4	1		
	80	328.8	1	251.5	1	328.4	2
	85	340.7	2	234.9	1		
	90	331.9	2	229.1	1	330.3	1
	95	324.5	1	249.3	1		
	100	334	3	236.7	1	336.5	3
	105	339.7	1	240.3	1		
	110	331	2	241.6	2	333.7	2
	115	335.7	1	247.8	1		
	120	322.5	1	241.5	1	322.2	2
	125	335.3	1	239.4	3		
	130	326.1	4	251.2	1	332.3	3
	135	332.4	1	240	1		
	140	328.1	1	243.1	1	329.8	3
	145	33.7	2	240.3	2		
	150	339.6	2	238.7	1	341.8	1
	155	328.9	2	237.5	1		
	160	329.3	1	237.1	2	325.4	1
	165	338	1	232.4	1		
	170	336	1	246.4	1	333.1	1
	175	321	2	226.9	1		
	180	315.5	2	240.4	2	313.9	2

Repeated measurments on different point of time.

Transmitter power: -6dB			Date: Time: Quality:		Date: Time: Quality:
Filename:		359_9_F1	5/26/94	359_9_F1	5/26/94
Disk setting:		359.9	10:40:03	359.9	15:20:53
Rounded disk setting:		180		180	
Calculated real bearing:		330		330	
Frequency:	20	142.3	1	144.7	3
	25			157.8	1
	30	146.7	1	146.9	1
	35			156	2
	40	147.1	1	146.8	1
	45			151.8	2
	50	148.3	1	154.3	1
	55			153.3	1
	60	165.4	2	164.8	2
	65			148.3	1
	70	157.7	2	158.3	1
	75			151.9	1
	80	148.5	2	149.9	2
	85			152.8	2
	90	163.6	1	164.4	1
	95			138.7	1
	100	155.8	1	155.3	1
	105			143.7	2
	110	148.3	1	149.4	2
	115			150.8	1
	120	145.2	2	145.9	2
	125			151.3	1
	130	148.3	2	150.1	2
	135			148.4	1
	140	147.6	2	147.2	1
	145			161.7	2
	150	149.5	3	147.3	3
	155			159.7	2
	160	154.4	2	152.8	2
	165			156.4	1
	170	150.5	1	152.4	1
	175			158.3	2
	180	150.3	1	149	1

Small frequency steps.

Transmitter power: -6dB			Date: Time: Quality:
Filename:		89_8_F1	5/26/94
Disk setting:		89.8	12:41:20
Rounded disk setting:		90	
Calculated real bearing:		60	
Frequency:	50	51.4	1
	51	60.8	2
	52	68	1
	53	67.7	2
	54	47.4	1
	55	61.7	2
	56	68	1
	57	55.2	1
	58	60.8	2
	59	71.3	1
	60	54.7	1
	61	60.5	2
	62	64.5	1
	63	58.9	2
	64	57.3	2
	65	71.8	1
	66	58.2	1
	67	62.2	1
	68	67.7	2
	69	49.8	2
	70	50.3	2
	71	67.7	2
	72	66.5	2
	73	48.6	1
	74	65.2	3
	75	70.9	1
	76	49.4	1
	77	60.8	3
	78	75.1	1
	79	61.5	2
	80	72.4	1

Appendix C Different power settings for the measurement transmitter

Direction finder receiver 1

	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:
Disk setting:			89.8	13:25:35			179.8	13:55:36			269.9	14:41:51			359.9	11:05:09
Rounded setting:			90				180				270					
Calculated bearing:			60				330				240					
	-12	30	69.8	2	-12	30	327.8	3	-12	30	247.2	2	-12	30	146.4	1
	0	30	70.3	1	0	30	328.4	2	0	30	247.7	1	0	30	146.8	1
	6	30	69.9	1	6	30	328.6	2	6	30	247.8	1	6	30	146.7	1
	-12	57	55.3	1	-12	57	322.3	1	-12	57	253.4	1	-12	57	164.8	1
	0	57	54.8	1	0	57	322.2	1	0	57	253.4	1	0	57	164.7	1
	6	57	54.9	1	6	57	322.1	1	6	57	253.3	1	6	57	164.8	1
	-12	84	65.9	2	-12	84	321.2	1	-12	84	247.4	2	-12	84	142.2	1
	0	84	65.8	2	0	84	320.9	1	0	84	247.3	2	0	84	142.1	1
	6	84	66.1	2	6	84	321.2	1	6	84	247.6	2	6	84	141.9	1
	-12	138	62.2	1	-12	138	332.1	2	-12	138	244.6	1	-12	138	158	1
	0	138	61.5	1	0	138	331.8	2	0	138	254.2	1	0	138	157.9	1
	6	138	62.8	1	6	138	331.8	2	6	138	245.1	1	6	138	158	7
	-12	144	66.2	2	-12	144	320.9	1	-12	144	235.5	1	-12	144	161.2	1
	0	144	66.5	2	0	144	321.8	1	0	144	235.5	1	0	144	162.2	1
	6	144	66.3	2	6	144	320.9	1	6	144	235.3	1	6	144	160.9	1

Direction finder receiver 2

	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:
Disk setting:			89.8	13:06:16			179.8	14:08:15			269.9	14:55:30			359.9	11:14:48
Rounded setting:																
Calculated bearing:																
	-12	30	69.7	2	-12	30	328.8	3	-12	30	246.8	2	-12	30	147.3	1
	0	30	69.5	1	0	30	328.6	2	0	30	247.5	1	0	30	147.3	1
	6	30	69.5	1	6	30	329.1	2	6	30	247.6	1	6	30	147.1	1
	-12	57	54.4	1	-12	57	321.4	1	-12	57	252.8	1	-12	57	165	1
	0	57	54.8	2	0	57	320.8	1	0	57	253.4	1	0	57	164.4	1
	6	57	54.6	1	6	57	322.3	1	6	57	253.1	1	6	57	164.6	1
	-12	84	64.8	2	-12	84	322.1	1	-12	84	247.1	2	-12	84	142.1	1
	0	84	65.7	2	0	84	321.7	1	0	84	247.2	2	0	84	141.9	1
	6	84	65.5	2	6	84	321.7	1	6	84	247.1	2	6	84	142.2	1
	-12	138	61.7	1	-12	138	331.2	2	-12	138	244.1	1	-12	138	158.3	1
	0	138	61.7	1	0	138	331.8	2	0	138	244.6	1	0	138	158	1
	6	138	61.9	2	6	138	331.8	2	6	138	244.4	1	6	138	158.4	1
	-12	144	66	2	-12	144	321	1	-12	144	235.4	1	-12	144	161	1
	0	144	65.6	2	0	144	320.5	1	0	144	235.1	1	0	144	160.8	1
	6	144	66.3	2	6	144	320.7	1	6	144	235.3	1	6	144	160.9	1

Direction finder receiver 3

	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:	Power [dB]	Frequency		Time: Quality:
Disk setting:			89.8	13:19:26			179.8	14:19:33			269.9	15:10:58			359.9	11:21:11
Rounded setting:																
Calculated bearing:																
	-12	30	69.5	2	-12	30	327.5	3	-12	30	248	2	-12	30	145.7	4
	0	30	70.1	1	0	30	328.4	2	0	30	247.7	1	0	30	146.2	1
	6	30	70.2	1	6	30	328.3	2	6	30	247.9	1	6	30	146.4	1
	-12	57	54.9	1	-12	57	321.6	1	-12	57	252.7	1	-12	57	164.4	1
	0	57	55.2	1	0	57	321.4	1	0	57	253	1	0	57	164.4	1
	6	57	55.2	1	6	57	321.5	1	6	57	252.7	1	6	57	164.3	1
	-12	84	64.8	2	-12	84	321.1	1	-12	84	246.5	2	-12	84	141.4	1
	0	84	64.9	2	0	84	321.1	1	0	84	247.5	2	0	84	141.5	1
	6	84	65.1	2	6	84	321	1	6	84	247.2	2	6	84	141.6	1
	-12	138	62.5	1	-12	138	331.7	2	-12	138	245.2	1	-12	138	158	1
	0	138	63.5	1	0	138	331.7	2	0	138	245.2	1	0	138	157.7	1
	6	138	63.1	1	6	138	331.6	2	6	138	245.1	1	6	138	157.9	1
	-12	144	66.5	2	-12	144	320.6	1	-12	144	235.5	1	-12	144	160.8	1
	0	144	66.4	2	0	144	320.8	1	0	144	235.2	1	0	144	161.2	1
	6	144	67	2	6	144	321	1	6	144	235.3	1	6	144	160.8	1

Appendix D Frequency measurements for direction finding receiver 2

Transmitter power: -6dB

		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:	89_8_F1	5/26/94	179_8_F1	5/26/94	0_0_F1	5/26/94	359_9_F1	5/26/94
Disk setting:	89.8	13:00:42	179.8	14:03:57	269.9	14:48:23	359.9	10:51:17
Rounded disk setting:	90		180		270		360	
Calculated real bearing:	60		330		240		150	
20	59.4	3	336.6	3	244.7	2	144.6	2
30	69.5	1	329.3	2	247.5	1	146.5	1
40	61	1	331.2	2	246.9	1	147.3	1
50	51.8	1	326.5	1	249.6	1	150.1	1
60	53.5	2	328.1	1	259.2	1	165.1	2
70	49.6	2	321.1	1	251.4	1	157.6	1
80	52.2	1	328.8	1	252.3	1	149.1	2
90	61.7	1	332.3	2	229.4	1	163.9	1
100	59.1	2	335.1	3	237.1	1	154.8	1
110	64.5	2	333	1	240.7	2	148.7	1
120	63	2	322.1	1	241.5	1	144.4	2
130	60.6	2	327.4	3	250.5	1	148.3	2
140	59.8	2	327.2	2	243.2	1	146.7	1
150	53.6	1	340.4	1	238.3	2	150.3	3
160	65.1	1	328.8	2	238.1	2	153.7	2
170	68.2	1	335.1	1	246	1	152.2	1
180	58.4	3	315.3	2	240	1	149.4	1

Appendix E Frequency measurements for direction finding receiver 3

Transmitter power: -6dB

		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:		Date: Time: Quality:
Filename:	89_8_F1	5/26/94	179_8_F1	5/26/94	269_9_F1	5/26/94	359_9_F1	5/26/94
Disk setting:	89.8	13:12:03	179.8	14:14:46	269.9	15:02:53	359.9	10:57:58
Rounded disk setting:	90		180		270		360	
Calculated real bearing:	60		330		240		150	
20	61	3	337.4	3	245.8	2	143.4	3
30	70.5	1	333	3	248.3	1	146.3	1
40	61.5	1	330.5	1	247.8	1	147	1
50	52.5	1	326.3	1	249.5	1	149.8	1
60	54.4	1	327.7	1	258.8	1	165.5	2
70	49.5	3	321.1	1	251.7	1	157.4	1
80	53.2	1	328.1	1	252.8	1	148.6	2
90	62.6	1	331.6	2	229.2	1	163.6	1
100	59.8	2	334.2	2	235.2	2	154.3	2
110	65	2	332.4	2	241.6	2	148.3	1
120	63.4	2	322.5	1	241.6	1	143.7	2
130	60.9	2	326.4	4	246.6	1	147.6	2
140	60.5	1	327.2	2	243.7	1	146.7	1
150	53.4	1	339.2	3	229.7	2	149.4	3
160	66.2	1	328.2	1	238.7	2	153.2	2
170	67.1	1	335.4	1	246.3	1	152.3	1
180	58.6	3	315.4	2	239.7	2	148.4	1

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Feasibility Study Measuring Facility for EW-Direction Finders of the Royal Dutch Army

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

De Royal Dutch Army has the need for measuring the accuracy of the EW direction finders of the ground based EW system. The intention is to inspect the direction finding accuracy of the operational direction finders periodically (every 1 or 2 years). In addition the mobilizable direction finders will be inspected one's every four years. Extensive measurements gave an insight in the feasibility of the development of a practical measurement facility. This report describes the preparations and results of this period of measurements which is held in may 1994 on the TNO-FEL test-site.
During the measurement period, the obtained results show quite large errors in bearing. The bearing error were not so much dependent on the used receiver or transmitter power, but much more of the used transmitter frequency. Because of the unexpected errors in the measurement results the main goal, setting up an accurate calibration test site, is unrealistic for the TNO test site. In order to get a better insight in the performance of the land based direction finder in the future, it is necessary to test these systems in different environments.

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